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Long-Life Assurance Test and Study Recommendations

Long-Life Assurance Study for Manned Spacecraft Long-Life Hardware

MARTIN MARIETTA

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LONG-LIFE ASSURANCE
TEST AND STUDY
RECOMMENDATIONS

LONG-LIFE ASSURANCE STUDY
FOR MANNED SPACECRAFT
LONG-LIFE HARDWARE

Approved

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This document is Volume V of a five-volume final report prepared by Martin Marietta Corporation, Denver Division for the National Aeronautics and Space Administration, Manned Spacecraft Center (NASA-MSC) under Contract NAS9-12359, *Long-Life Assurance Study for Manned Spacecraft Long-Life Hardware*. This study was performed with J. B. Fox, Manned Spacecraft Center, as Technical Monitor and R. W. Burrows, Martin Marietta, as Program Manager. Acknowledgment is made to the individual contributors identified in each volume and to R. A. Homan and J. C. DuBuisson, Task Leaders for the electrical/electronic and mechanical areas, respectively.

The five volumes submitted in compliance with Data Requirements List T-732, Line Item 4, are as follows:

Volume I - Summary of Long-Life Assurance Guidelines;

Volume II - Long-Life Assurance Studies of EEE Parts and Packaging;

Volume III - Long-Life Assurance Studies of Components;

Volume IV - Special Long-Life Assurance Studies;

Volume V - Long-Life Assurance Test and Study Recommendations.

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Table

I. INTRODUCTION

This volume recommends additional study and test efforts pertinent to the subject of long-life assurance. These additional tasks are presented in the order of recommended priority based upon need and cost effectiveness.

For reference purposes, the subjects studied in the basic contract are listed in Table 1.

Table 1 List of Completed Studies

Volume I	Summary of Long-Life Assurance Guidelines
Volume II	Long-Life Assurance Studies of EEE Parts and Packaging Monolithic Integrated Circuits Hybrid Integrated Circuits Transistors Diodes Capacitors Relays Switches and Circuit Breakers Electronic Packaging
Volume III	Long-Life Assurance Studies of Components Electric Motors and Bearings Accelerometers Gyroscopes and Bearings Compressors and Pumps Magnetic Tape Recorders Plumbing Components and Tubing Check Valves Pressure Regulators and Solenoid Valves Thermal Control Valves Pressure Vessels and Positive Expulsion Devices Ni-Cd Batteries Transducers
Volume IV	Special Long-Life Assurance Studies Temperature Cycling as Employed in the Production Acceptance Testing of Electronic Assemblies ("Black Boxes") Accelerated Testing Techniques Electronic Part Screening Techniques Industry Survey of Electronic Part Derating Practice Vibration Life Extension of Printed Circuit Board Assemblies Tolerance Funnelling and Test Requirements

II. RECOMMENDATIONS FOR ADDITIONAL STUDIES AND TESTS

A. EXPANSION OF EXISTING STUDY

The following subjects were not studied in the basic contract and are pertinent to the issue of long-life assurance. The list constitutes the candidate studies to consider in the planning of additional effort.

Small rocket engines;
Ordnance equipment;
Vidicons;
Traveling wave tubes;
Photomultiplier tubes;
Gas generators;
Silver-zinc batteries;
Silver-cadmium batteries;
Complex computers;
Extendable structures;
Solar cells;
Thermal control coatings;
photographic film;
Optical glass;
Meteoroid penetration;
Stress corrosion;
Van Allen radiation;
Electronic worst-case analyses;
Mechanical worst-case analyses.

B. UPDATING OF EXISTING STUDY REPORTS

It is proposed that in the planning of additional effort, the first follow-on contract should expand the scope of the work as previously described. For the second follow-on contract, it is proposed that the entire study be reviewed and updated to include the developments and data that have accrued since mid-1972. In this way, a complete and up-to-date bible of long-life technology would be available for use on the Shuttle Program and all other aerospace programs requiring high reliability and long-life.

An alternative approach, funding permitting, would be to concurrently accomplish both the expansion of the study and the updating effort.

C. GUIDELINES FOR DESIGNING TO SEVERE DYNAMIC REQUIREMENTS

The severe acoustic and vibration requirements for the current configuration of the Space Shuttle, coupled with the requirement to qualify the hardware for the long-time durations of many missions, is one of the most formidable problems of the Shuttle Program. It is proposed that guidelines be developed for the use of all contractors supplying hardware to the Shuttle Program. These guidelines would present information on various types of hardware and summarize, for each type, the guidelines that should be employed for the development of hardware capable of meeting the severe requirements that are expected to be levied against the Space Shuttle hardware.

D. INVESTIGATION OF IN-SPACE FAILURES DUE TO LIFE LIMITATIONS

Some of the spacecraft failures during flight were caused by either wearout or calendar aging. It would be desirable to determine what failures were due to the life limitations of hardware and what corrective action is necessary to prevent reoccurrence of these failures on new programs. To limit the scope of the study and investigate potentially more productive areas, it is suggested that only spacecraft that have functioned in space four or more years be studied.

Possible candidates for investigation are as tabulated:

Spacecraft	Operational Duration, Years
Transit 4A	8+
Syncom	6+
Vangard 1	6
Tiros 7	5
Syncom 3	5
ESSA 2	4+
Explorer 31	4
Pioneer 6	4
Early Bird	3 3/4

The proposed approach is as follows:

1) Identify in-space failures of all unclassified spacecraft that have operated for longer than four years via a literature and telephone survey;

2) Select the spacecraft that appears more promising for detailed study;

3) For each in-space failure identified, it should be ascertained which anomalies are relateable to either calendar aging or wearout. This would be determined by examination of in-flight data, prelaunch records and manufacturing histories;

4) Only those failures caused by aging or wearout will be studied in depth.

The report would summarize the results of the effort and delineate specific guidelines for long-life assurance of the generic categories studied.

E. ACCELERATED TESTING OF SEMICONDUCTORS

The accelerated testing study of Volume IV concluded that the accelerated test approaches developed by Bell Laboratories has potential application providing their practice of higher temperature burn-in of semiconductors could be implemented without extensive expenditure of funds for additional R&D testing. It is proposed that consideration be given to placing a contract with Bell Laboratories to develop the methods and means of using their accelerated test technology on the Shuttle Program in a manner designed to minimize both the emotional impact and the cost impact on the potential suppliers of the Shuttle Program hardware.

F. FAN LIFE VERIFICATION

In general, maximum life tests of fans have not been conducted. As indicated in Chapter V, Volume III, truncated life tests are normally employed; the duration of these tests are for only the mission duration plus a safety margin. For long-life missions,

it will be necessary to determine if fan lives can meet long-life space mission requirements and to determine what corrective measures, if any, are needed to meet life requirements.

It is proposed that surplus fans from the Apollo and Skylab programs be subjected to life tests to ascertain their maximum lives and to verify the failure modes and mechanisms.

G. ACCELERATED TESTING OF SOLID TANTALUM CAPACITORS

A progressive stress test of solid tantalum capacitors is recommended to find the voltage limits and to determine the accelerated life test correlation factors. Ninety screened parts would be employed. First, the voltage limits would be determined by constant stress tests. Next, three groups of 30 each would be run at three different stress levels determined by the voltage limit tests. Maximum stress is estimated to be 300% of rated voltage. Finally a Weibel test (analysis) would be run next on all three groups to determine the correlation factor.

H. ACCELERATED TESTING OF TEFLON VALVE SEATS

Cold flow or creep of Teflon can occur during long dormant periods with the seat under load. The cold flow can be accelerated by increasing the temperature. Initial analysis indicate that valve seats under normal loads for two weeks at 300°F should demonstrate an age equivalence of about 10 years, but this conclusion has not been substantiated with test data.

The proposed test program would develop an accelerated test method for Teflon valve seats.

I. DEVELOPMENT OF A HEALING APPROACH FOR SOLID TANTALUM CAPACITORS

Normal burn-in testing does not adequately screen solid electrolyte capacitors in regard to capability for operation under transient conditions. Use of an optimized healing technique has potential for application as a screen or as a conditioning test to improve

the capability of solid capacitors, to increase the long-life reliability, and to improve their usefulness by reduction of the series limiting impedance requirements. The technique successfully used on thin film solid electrolyte capacitors to optimize healing should be theoretically applicable to solids.

It is recommended that research be conducted to develop an optimizeed healing approach for solid-electrolyte-discrete-capacitors, using controlled step application of power and voltage. The purpose is to fully use the potential capability of existing capacitor types by both eliminating devices not capable of sufficient healing, and providing optimum healing of superior devices with fewer defects in order to advance the long-life assurance of solid tantalum capacitors. It is recommended that this research include:

1) Determination of an approach to obtain optimized healing;

2) Determination of optimized healing on characteristics of capacitance and dissipation factor;

3) Determination of improvement in surge current and voltage capability, together with feasibility of decreasing circuit resistance requirements;

4) Comparison of optimized and nonoptimized capacitor reliability by means of a Weibull analysis that uses accelerated life tests.

J. ELECTROMIGRATION MODEL VERIFICATION

The major semiconductor wearout mechanism is that of electromigration. Accurately modeling the electromigration phenomena will enable precise determination of this effect on life and permit derivation of metallization design guidelines based on physical principles as opposed to empirical data alone.

A statistical model was developed by J. D. Venables and R. G. Lye of Martin Marietta Corporation. The broad scope of agreement achieved and the apparent resolution of inconsistencies reported in the previous electromigration literature by the new model strongly indicates that it may be useful for quickly and accurately evaluating the expected life times of metallized stripes. It is recommended that a test program be conducted to test and verify the model. Tests should be performed to evaluate the following:

1) The effects of different degrees of thermal contact between the metallization and substrate;

2) The temperature dependence of mean time to failure, T_F. The model predicts that T_F is a complex function of the baseline temperature and exhibits an apparent actuation energy that varies with current density;

3) The behavior of T_F as a function of the baseline current density, j_o. The model predicts a relation between T_F and j_o that is considerably more complex than the power law dependence previously assumed by many investigators;

4) The realtionship between T_F and the grain size of the metallization.